Concentrations and seasonal dynamics of dissolved organic carbon in forest floors of two plantations (*Castanopsis kawakamii* and *Cunninghamia lanceolata*) in subtropical China

ZHANG Jiang-shan[1], GUO Jian-fen[2], CHEN Guang-shui[2], QIAN Wei[2]
[1] *Research Institute of Environmental Science, Fujian Normal University, Fuzhou 350007, P. R. China*
[2] *Key Laboratory of Subtropical Resources and Environments of Fujian Province, Fuzhou 350007, P. R. China*

Abstract: The concentrations and seasonal dynamics of DOC in forest floors of monoculture plantations of *Castanopsis kawakamii* and Chinese fir (*Cunninghamia lanceolata*) were assessed in Sanming, Fujian, China (26°11'30"N, 117°26'00"E). Forest floor samples were taken in January, April, July and October in 2002 and divided into undecomposed material (horizon Oi), partially decomposed organic material (horizon Oe), and fully decomposed organic material (horizon Oa). Upon collection, DOC concentrations of samples were analyzed by a High Temperature TOC. The results showed that the annual average DOC concentration of Chinese fir (1341.7 mg·kg^{-1}) in the forest floor was higher than that of *Castanopsis kawakamii* (1178.9 mg·kg^{-1}). Difference in DOC concentrations was observed among three horizons of the forest floor. DOC concentration of forest floor in the two forests was the highest in horizon Oe. Seasonal trends of DOC concentrations in different horizons of forest floors were similar and the maximal value occurred in autumn (or winter). The concentration and temporal change of DOC in studied forests were probably related to the variation in moisture, temperature, biological activity and quantity of organic matter in the forest floor.

Keywords: Dissolved organic carbon (DOC); Seasonal dynamics; Forest floor; *Castanopsis kawakamii*; *Cunninghamia lanceolata*; Monoculture plantation
CLC number: S715.9; S791.27 **Document Code**: A **Article ID**: 1007–662X(2005)03–0205-04

Introduction

The significance of dissolved organic carbon (DOC) in forest ecosystems has been highlighted because of its ecological function in nutrient and element cycling (Michalzik *et al.* 1999; Kalbitz *et al.* 2000; Neff *et al.* 2001). In forest ecosystems, the forest floor has been identified as a primary source for DOC (Qualls *et al.* 1991; Currie *et al.* 1996; Yang *et al.* 2004b). DOC released from the forest floor has great implications for the belowground C cycle, because the leaching loss of DOC can account for a substantial portion of the annual litterfall Carbon (Qualls *et al.* 1991; Hongve *et al.* 2000) and total forest floor C loss (Vance *et al.*1991). This leachate C loss from the forest floor has often been overlooked in determining soil C budgets, while the forest floor is receiving much attention due to its role as a temporary sink for increased litter C inputs following CO_2 enrichment (Schlesinger *et al.* 2001) or reforestation (Richter *et al.* 1999). Many attempts have been made to estimate the concentrations and fluxes of DOC in forest floors of many forests ecosystems, largely in temperate and tropical forests (Michalzik *et al.*1999; Michalzik *et al.* 2001; Park *et al.* 2003), a relative few studies have been done on forests of southern China, an area of the most important world subtropical forests.

In southern China, large-scale of natural forests have been converted to monoculture plantations (mainly economical conifers) following forest land clear-cutting, slash burning, and soil preparation. Currently, difference in vegetation composition, soil fertility, litterfall amount and its nutrient return, fine root production and turnover between plantations of *Castanopsis kawakamii* and Chinese fir (*Cunninghamia lanceolata*) have been examined (Lin *et al.* 1986; Yang *et al.* 1993, 2003, 2004a). The objective of this study was to determine DOC concentration and its seasonal dynamics in forest floor layer leachates of two plantation forests (*C. kawakamii* and Chinese fir).

Site description

This study was carried out in the Xiaohu work-area of the Xinkou Experimental Forestry Centre at Fujian Agricultural and Forestry University, Sanming, Fujian Province, China (26°11'30"N, 117°26'00"E). It borders the Daiyun Mountain on the southeast, and the Wuyi Mountain on the northwest. The region has a middle sub-tropical monsoonal climate, with a mean annual temperature of 25 °C and a relative humidity of 81%. The mean annual precipitation is 1749 mm, mainly occurring from March to August, and the mean annual actual evapotranspiration is 1585 mm (Fig. 1), (Yang *et al.* 2003, 2004a). The growing season is relatively long with an annual frost-free period of around 330 days. The parent material of the soil is acidic sandy shale and soils are classified as red soils (Humic Planosols in the FAO system). Thickness of the soil usually exceeds 1.0 m.

Two adjacent plantations consisting of *C. kawakamii* and Chinese fir were investigated. Both of *C. kawakamii* and Chinese fir were derived from a natural forest (*C. kawakamii*). A part of natural forest was clear-cut and planted with *C. kawakamii* and Chinese fir 33 years ago. Selected forest characteristics and some properties of the surface soil (0–20 cm) of the two forests are described in Table 1 (Yang *et al.* 2003, 2004a).

Foundation item: This study was supported by the Teaching and Research Award program for MOE P.R.C. (TRAPOYT)
Biography: ZHANG Jiang-shan (1946-), male, Researcher in Fujian Normal University, Fuzhou 350007, P. R. China. Email: jszhang@fjnu.edu.cn
Received date: 2004-10-27
Accepted date: 2004-12-23
Responsible editor: Zhu Hong

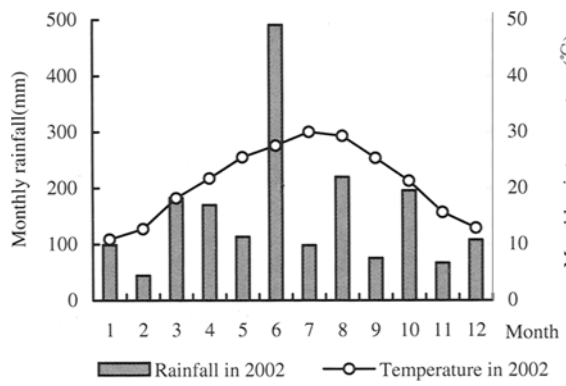

Fig. 1 Monthly changes of rainfall and air temperature in the studied sites in 2002

Table 1. Forest characteristics and soil properties in the *Castanopsis kawakamii* and Chinese fir

Parameters	Forest type	
	C. kawakamii	Chinese fir
Stand characteristics		
Mean tree height (mean±SE n=15, m)	18.9±1.5	21.9±1.8
Mean tree diameter at breast height (mean±SE n=15, cm)	23.4±2.2	23.3±2.1
Stand density (stem·hm^{-2})	875	1117
Stand volume (m^3·hm^{-2})	412.431	425.912
Biomass of shrub layer (t·hm^{-2})	0.780	1.993
Biomass of herb layer (t·hm^{-2})	0.292	2.478
Thickness of forest floor (cm)	4±2	2±1
Soil (top 0-20cm) properties		
Bulk density (g·cm^{-3})	1.10	1.20
Water content (%)	24.86	24.54
Organic matter (g·kg^{-1})	29.8	29.5
Total N (g·kg^{-1})	1.12	1.12
Total P (g·kg^{-1})	0.31	0.29
Hydrolyzable N (mg·kg^{-1})	115.2	110.3
Available P (mg·kg^{-1})	5.92	4.69
Available K (mg·kg^{-1})	96.7	61.8

Materials and methods

Sample collection and analysis

Three plots of 20 m×20 m were randomly established at the midslope position in each forest. In each plot, forest floor samples were taken in January, April, July and October in 2002 using thirty subplots of 50 cm×50 cm. These subplots were systematically located at three horizontal lines on the top, middle and low slope positions, respectively. The forest floor layer was divided into undecomposed material (horizon Oi), partially decomposed organic material (horizon Oe), and fully decomposed organic material (horizon Oa). The samples were taken in horizons and the material at horizon Oa was sieved through a 2-mm-mesh screen to exclude some mineral components. An aliquot of samples was oven-dried (80°C) to determine the initial moisture content and the rest was stored in polyethylene bags at 5 °C for approximately 2 weeks. The DOC concentration was adjusted to an oven-dry basis.

Forest floor sample (horizon Oi, Oe and Oa respectively) of 10 g was shaken with deionized water of 100 mL on a side by side shaker for 5 h and then filtered through a membrane filter with 0.45-μm pores. The extracts were measured for DOC concentration using a High Temperature TOC (Elementar Analysensysteme GmbH, Germany) within 24 h. Analyses were carried out in triplicate.

Statistical analyses

Difference in DOC concentrations in three horizons (horizon Oi, Oe, and Oa) between forests was analyzed with the *t* test. Significance levels were set at $P<0.05$ for all tests.

Results

DOC concentrations in forest floor

During the time period sampled, difference in average DOC concentrations in three horizons between forests was not significant and mean annual DOC concentration of the forest floors (horizon Oi, Oe and Oa) was 1178.9 and 1341.7 mg·kg^{-1} in the *C. kawakamii* and Chinese fir plantations, respectively. In general, DOC concentrations in the forest floor of the Chinese fir were higher than those of the *C. kawakamii* except for DOC concentration in horizon Oa (Table 2). Among three horizons, horizon Oe had the highest DOC concentration followed by the horizon Oi and Oa for both forests (Table 2).

Table 2. Annual average concentration of DOC in different horizons of forest floor (mean±SE) (mg·kg^{-1})

Horizon	*C. kawakamii*	Chinese fir
Oi	1053.9±160.2a	1202.1±156.1a
Oe	1987.5±386.2a	2349.7±335.8a
Oa	495.2±90.8a	473.2±85.3a
Average	1178.9±219.4a	1341.7±220.6a

Note: Different letters on the same row indicate significant differences between forests at $P<0.05$.

Seasonal pattern

There was significant seasonal variation in DOC concentrations of forest floors for both forests except for horizon Oa where relatively constant DOC concentrations were found during the year (Fig. 2). Seasonal variations of DOC concentrations were similar in horizon Oe and Oa of the Chinese fir with a sequence of winter > autumn > summer > spring. While in horizon Oi, DOC concentration decreased in the order of autumn > winter > summer > spring (Fig. 2). For the Chinese fir, a peak of DOC concentration in horizon Oe and Oa occurred in autumn, and in horizon Oi, the highest DOC concentrations appeared in winter (Fig. 2). During four seasons, DOC concentrations in horizon Oe of the *C. kawakamii* and Chinese fir plantations were consistently higher than those in horizon Oi and Oa (Fig. 2).

Discussion

DOC concentrations in the forest floor

In this study, annual average DOC concentrations in the forest floor of both forests were in the range of 839–3514 mg·kg^{-1} for various forests in the world (Huang *et al.* 1996), while the mean DOC concentrations in forest floor of the *C. kawakamii* and Chinese fir plantations (Table 2) were lower than those of temperate forests (1603–1820 mg·kg^{-1}), (Michalzik *et al.* 2001). As the average temperature in the study area was 25 °C, degradation of organic matter might be faster and more complete than that in

temperate regions, thus resulting in a relatively low concentration of DOC.

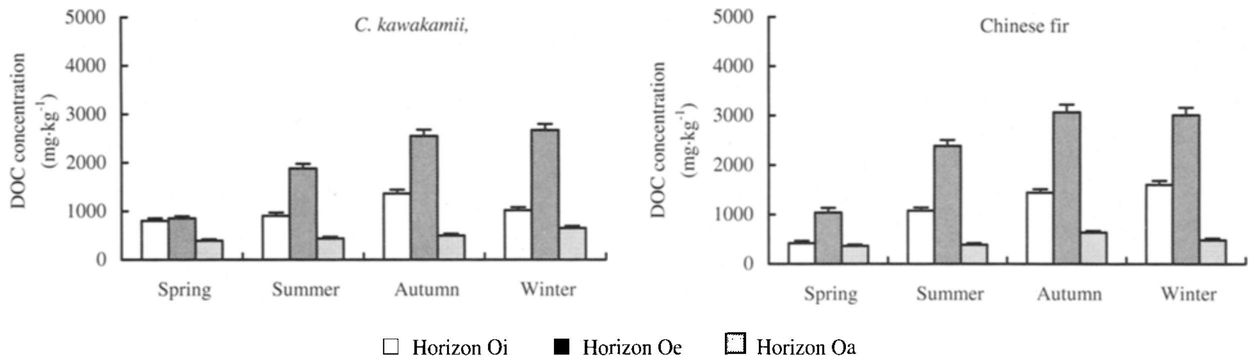

Fig. 2 Seasonal variation in DOC concentrations in forest floors of the *C. kawakamii* and Chinese fir. Bars refer to one standard error

The DOC concentrations in the forest floor under the Chinese fir plantation were higher in comparison with those under the *C. kawakamii* plantation due to the following factors: higher stand density in the Chinese fir, organic matter quality characteristics or relative low rates of mineralization providing a greater organic matter mass of the forest floors for DOC supply. This is similar to other studies (Cronan *et al.* 1985; Currie *et al.*1996; Currie *et al.* 1997). For example, Currie *et al.* (1996) found higher DOC concentrations in forest floor under coniferous trees as compared to broadleaved one. Cronan (1990) pointed out that DOC concentration from coniferous forests was 50% higher than that from hardwood stands. Further, DOC concentration in the forest floor was highly variable among different horizons. DOC concentration in the Oe layer was higher than that in the Oi layer, which is similar to the results reported by Zsolnay (1996) and McDowell & Likens (1988). They proposed that partly decomposed organic matter in the forest floor is the major source of DOC rather than fresh litter. While in horizon Oa of both forests, DOC concentrations were the lowest, which suggested that there was likely a large adsorption or decomposition of DOC in horizon Oa.

Seasonal variations in DOC concentrations in the forest floor

Dissolved organic carbon (DOC) in forest floor leachate varies seasonally (Currie *et al.* 1996; Michalzik *et al.* 1999; Kaiser *et al.* 2001). Michalzik & Matzner (1999) reported different seasonal variations for DOC concentrations in forest floors under coniferous forests. We found that concentrations of DOC decreased in the forest floor in summer (or spring), compared with those in winter (or autumn). This decrease was attributed to mineralization increasing or leaching loss in warmer summer (or spring). DOC itself can serve as a substrate for microorganisms. In autumn or winter, the mineralization of DOM was less due to low soil temperature, thus more DOC was accumulated. Further, the leaching of DOC increased as the precipitation and water fluxes increased in several field and laboratory studies (McDowell *et al.* 1988; Christ *et al.* 1996). In South China, the large amount of precipitation was concentrated in spring or summer during the course of the year (Fig. 1), thus intensive leaching of potentially soluble material from the organic forest floor layer may easily occurred. In laboratory studies, it was also shown that intensive and repeated leaching of forest floor material reduced the concentrations dissolved organic C (Christ *et al.* 1996).

The seasonality of DOC concentration in forest floor leachates in our study is different to the findings by Scott *et al.* (1998), McDowell *et al.* (1998) and Tipping *et al.* (1999). They found that DOC concentration in the forest floor in summer was higher than that in winter. These results show that seasonal pattern of DOC concentration can be highly variable. A few studies have been done further and found that seasonal changes in the concentration of DOC in forest floor leachates were directly related to litterfall inputs (Lundström 1993; Casals *et al.* 1995; Currie *et al.* 1996). However, the seasonality of DOC concentration in forest floor leachates in this study was found to be independent of the litterfall dynamics (Yang *et al.* 2004), in contradiction to other field studies reporting a positive response (Lundström 1993; Casals *et al.* 1995; Currie *et al.* 1996). Our concentration dynamics may be caused by other factors, such as drying and rewetting, temperature and site specific properties (e.g. nutrient status, litter quality and microbiology), (Michalzik *et al.* 2001). Also, these environmental and biotic factors may interact at the same time (Kaiser *et al.* 2001; Kawahigashi *et al.* 2003).

Conclusions

Annual average concentration of DOC in forest floor leachates of the Chinese fir plantation was higher than in that of the *C. kawakamii* plantation. Also, DOC in the forest floor of both forests showed a similar vertical pattern. Horizon Oe had the highest DOC concentration among different horizons. In addition to a vertical pattern, DOC concentration varied temporally. High mineralization rates or leaching loss in summer (or spring) would decrease the DOC concentration in the forest floor, while relative accumulation of litterfall in the winter (or autumn) due to low temperature and moisture would increase DOC. Overall, DOC concentration and its seasonal changes in the forest floor may be different among forest types. Thus more long-term studies are necessary.

References

Casals, P., Romanya, J., Cortina, J., *et al.* 1995. Nitrogen supply rate in Scots pine (*Pinus sylvestris* L.) forests of contrasting slope aspect [J]. Plant and Soil, 168–169: 67–73.

Christ, M.J., David, M.B. 1996. Temperature and moisture effects on the production of dissolved organic carbon in a spodosol [J]. Soil Biology & Biochemistry, **28**: 1191–1199.

Cronan, C.S. 1990. Patterns of organic acid transport from forested water-

sheds to aquatic ecosystems [C]. In: EM Perdue, ET Gjessing (eds). Organic Acids in Aquatic Ecosystems. Life Sciences Research Report 48. John Wiley and Sons Ltd., Chichester, pp.245–260.

Cronan, C.S., Aiken, G.R. 1985. Chemistry and transport of soluble humic substances in forested watersheds of the Adirondack Park, New York [J]. Geochim. Cosmochim. Acta, **49**: 1697–1705.

Currie, W.S., Aber, J.D. 1997. Modeling leaching as a decomposition process in humid montane forests [J]. Ecology, **78**(6): 1844–1860.

Currie, W.S., Aber, J.D., McDowell, W.H., *et al.* 1996. Vertical transport of dissolved organic C and N under long-term N amendments in pine and hardwood forests [J]. Biogeochemistry, **35**: 471–505.

Hongve, D., Van Hees, P.A.W. and Lundström, U.S. 2000. Dissolved components in precipitation water percolated through forest litter [J]. European Journal of Soil Science, **51**: 667–677.

Huang, W.Z., Schoenau, J.J. 1996. Distribution of water-soluble organic carbon in an aspen forest soil [J]. Canadian Journal of Forest Research, **26**: 1266–1272.

Kaiser, K., Guggenberger, G., Haumaier, L., *et al.* 2001. Seasonal variations in the chemical composition of dissolved organic matter in organic forest floor layer leachates of old-growth Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) stands in northeastern Bavaria, Germany [J]. Biogeochemistry, **55**: 103–143.

Kalbitz, K., Solinger, S., Park, J.H., *et al.* 2000. Controls on the dynamics of dissolved organic matter in soils: a review [J]. Soil Science, **165**(4): 277–304.

Kawahigashi, M., Sumida, H., Yamamoto, K. 2003. Seasonal changes in organic compounds in soil solutions obtained from volcanic ash soils under different land uses [J]. Geoderma, **113** : 381–396.

Lin Peng, Qiu Xizhao. 1986. Study on the *Castanopsis kawakamii* forest in the Wakeng area of Sanming city, Fujian province [J]. Acta Phytoecol. Geobot. Sinica, **10**(4): 241–252. (in Chinese)

Lundström, U.S. 1993. The role of organic acids in the soil solution chemistry of a podzolized soil [J]. Journal of Soil Science, **44**: 121–133.

McDowell, W.H., Currie, W.S., Aber, J.D., *et al.* 1998. Effects of chronic nitrogen amendments on production of dissolved organic carbon and nitrogen in forest soils [J]. Water, Air and Soil Pollution, **105**: 175–182.

McDowell, W.H., Likens, G.E. 1988. Origin, composition and flux of dissolved organic carbon in the Hubbard Brook Valley [J]. Ecological Monographs, **58**: 177–195.

Michalzik, B., Kalbitz, K., Park, J.H., *et al.* 2001. Fluxes and concentrations of dissolved organic carbon and nitrogen – a synthesis for temperate forests [J]. Biogeochemistry, **52**: 173–205.

Michalzik, B., Matzner, E. 1999. Dynamics of dissolved organic nitrogen and carbon in a central European Norway spruce ecosystem [J]. European Journal of Soil Science, **50**: 579–590.

Neff, J.C., Asner, G.P. 2001. Dissolved organic carbon in terrestrial ecosystems: synthesis and a model [J]. Ecosystems, **4**: 29–48.

Park, Ji-H., Matzner, E. 2003. Controls on the release of dissolved organic carbon and nitrogen from a deciduous forest floor investigated by manipulations of aboveground litter inputs and water flux [J]. Biogeochemistry, **66**: 265–286.

Qualls, R.G., Haines, B.L. 1991. Geochemistry of dissolved organic nutrients in water percolating through a forest ecosystem [J]. Soil Science Society of America Journal, **55**: 1112–1123.

Qualls, R.G., Haines, B.L., Swank, W.T. 1991. Fluxes of dissolved organic nutrients and humic substances in a deciduous forest [J]. Ecology, **72**: 254–266.

Richter, D.D., Markewitz, D., Trumbore, S.E., *et al.* 1999. Rapid accumulation and turnover of soil carbon in a re-establishing forest [J]. Nature, **400**: 56–58.

Schlesinger, W.H., Lichter, J. 2001. Limited carbon storage in soil and litter of experimental forest plots under increased atmospheric CO_2 [J]. Nature, **411**: 466–468.

Scott, M.J., Jones, M.N., Woof, C., *et al.* 1998. Concentrations and fluxes of dissolved organic carbon in drainage water from an upland peat system [J]. Environment International, **24**: 537–546.

Tipping, E., Woof, C., Rigg, E., *et al.* 1999. Climatic influences on the leaching of dissolved organic matter from upland UK moorland soils, investigated by a field manipulation experiment [J]. Environment International, **25**: 83–95.

Vance, G.F., David, M.B. 1991. Forest soil response to acid and salt additions of sulfate: III. Solubilization and composition of dissolved organic carbon [J]. Soil Science, **151**: 297–305.

Yang Yusheng, Chen Guangshui, Lin Peng, *et al.* 2003. Fine root distribution, seasonal pattern and production in a native forest and monoculture plantations in subtropical China [J]. Acta Ecologica Sinica, **23**(9): 1719–1730. (in Chinese)

Yang Yusheng, Li Zhenwen, Liu Aiqin, *et al.* 1993. Studies on soil fertility for natural forest of *Castanopsis kawakamii* replaced by broadleaf plantation [J]. Journal of Northeast Forestry University, **21**(5): 14–21. (in Chinese)

Yang Yusheng, Lin Ruiyu, Li Tingbo, *et al.* 2004b. Ultraviolet-visible spectroscopic characteristics of dissolved organic matter released from forest litterfall [J]. Journal of Tropical and Subtropical Botany, **12**(2): 124–128. (in Chinese)

Yang Yusheng, Guo Jianfen, Chen Guangshui, *et al.* 2004a. Litterfall, nutrient return, and leaf-litter decomposition in four plantations compared with a natural forest in subtropical China [J]. Annals of Forest Science, **61**: 465–476.

Zsolnay, A. 1996. Dissolved humus in soil waters [C]. In: Piccolo A (Ed.) Humic Substances in Terrestrial Ecosystems. Elsevier Science B.V., pp 171–223.